From Laboratory to Museum

Displaying Scientific Discovery With a Lab Notebook

Elizabeth M. Molacek
Edith O'Donnell Institute of Art History
University of Texas at Dallas

Aaron M. Fond
Physician Fellow in Gastroenterology
UT Southwestern Medical Center

A key component of any research process is documentation and record-keeping, so that results and conclusions can be shared as well as verified. In the sciences, this record takes the form of the lab notebook—traditionally a physical notebook with handwritten notes that document the scientific process and resulting knowledge produced by the entire lab. Lab notebooks document a process and thus rarely provide a final conclusion, or especially the sought after 'aha' moment that occupies public imagination. The reality is that the day-to-day of research is usually boring, iterative, and messy, and a lab notebook is a space to house this process. Despite their essential role in the research process, lab notebooks rarely make it to the headlines. During the COVID pandemic, with the demand for fast, new knowledge and cures, the scientific research *process* has been atypically thrust into the 24-hour news-cycle. This intense focus on research has amplified the huge divide between what we, the public, want—objective proof and conclusions—and the fuzzy, gray reality of research, which must be interpreted, re-investigated, debated, and confirmed until an overwhelming abundance of evidence leads to a consensus. This ambiguous reality is expressed in a recent article about a faux disease model for a hypothetical epidemic, cheekily dubbed Simulitis, giving readers the chance to "model some scenarios—and see what epidemiologists are up against as they race to understand a new contagion."[1] The reader adopts the role of scientist and uses the model to estimate the number of expected cases—with the caveat that "so much information remains unknown and is changing at a rapid pace." In other words, there is no single conclusion because scientific research is messy. With the widespread realization that scientific knowledge is not a single set of facts, but a moving body of knowledge, the focus has

1 H. Stevens and J. Muyskens, "Disease modelers are wary of reopening the country. Here's how they arrive at their verdict." *Washington Post*, May 24, 2020, www.washingtonpost.com/graphics/2020/health/disease-modeling-coronavirus-cases-reopening.

shifted slightly from celebrating the 'aha' to explaining the processes leading up to that discovery, as they emerge from the many moments included in a lab notebook. The Simulitis model does this in a small way, but a more comprehensive example exists at the Perot Museum of Nature and Science in Dallas, where the laboratory notebook of Nobel Laureate Bruce Beutler is on long-term display. Like any lab notebook, Beutler's notebook records his original data, but as will be discussed below, it now provides insight into the process leading to his momentous discovery and serves as an inspiration to younger generations of scientists. Examining this notebook provides a potential model for narrowing the gap between perception and reality of scientific research processes, by bringing the laboratory directly into the museum.

The Beutler notebook seems like an average, used computation notebook, the type that can be easily purchased at any university supply store. For anyone who has ever taken an introductory biology or chemistry course, the lab notebook looks relatively familiar—it has slightly green-tinted, quad-ruled pages that you'd use to record your work. Even for those who have never set foot in a lab, notebooks are commonplace, everyday objects—certainly not something you'd expect to find in a museum display case. The Beutler notebook is unique, however, because it is not on display to convey certain, important scientific facts or specific concepts—the content on the pages is barely legible—but instead, to emphasize the *development* of scientific knowledge (Figure 1). Museums have always served as spaces that collect, display, and create knowledge and with objects such as the Beutler notebook, they also illustrate the process of scientific discovery.

Bruce Beutler was awarded the Nobel Prize in Physiology or Medicine in 2011, along with Jules Hoffman and Ralph Steinman, for their research on innate immunology, the ability of the immune system to recognize pathogens without any previous priming or direction. Unlike the mechanism that vaccines co-opt to teach the immune system what is dangerous and should be fought, the innate immune system is born ready, inherently suspicious of pathogens. At the Perot Museum, Beutler's notebook is part of an installation dedicated to Nobel laureates in the biosciences from the Dallas region, including Bruce Beutler, Alfred Gilman, Johann Diesenhofer, Joseph Goldstein, and Michael Brown (Figure 2). Each laureate is represented by an over-life-sized headshot, a short description of his area of study, his Nobel prize, and at least one physical memento signifying the scientific discovery leading to the prize. For several of the laureates, this memento is some sort of model representing their research: e.g., a 3D printed protein. For Beutler, the lab notebook serves this purpose—it contains research that led to his Nobel prize, and the specific pages on view record a significant moment during that research process.

In its current display, the notebook could easily be overlooked, or seen simply as a token of a specific period in Beutler's research career. A label identifies each of the objects in the case with basic information including title and lender, but provides no explanatory information about the background or significance of each item. For a visitor unfamiliar with the scientific research process or the research itself, the notebook would likely be unfamiliar. It is opened to show a spread of two pages that were integral to the Nobel-winning research. In fact, the two pages record a moment in time when the researchers realized they had made a significant discovery. The pages display a series of handwritten notations around six rectangular photos of nucleic acid electrophoresis gels, which show the separation of DNA fragments by size (Figure 3). Many of the notes written on the pages provide mundane details of the experiments—things a researcher would write

Figure 1 Installation view of the Nobel Exhibition in the Being Human Hall at the Perot Museum of Nature and Science, as displayed 2020. Copyright Perot Museum of Nature and Science

as a record for future reference—but across the top of the left page in large, all-capital letters are the words: "TOLL, TOLL, TOLL." These three words, although referencing a specific scientific observation, also mark the researcher's realization that the data revealed a long sought-after receptor in mice—called Toll-like receptor 4—that led to the lab's eventual Nobel prize. The identification of Toll-like receptor 4 resulted in a revolutionary new understanding of the human immune system—one that was evolutionarily conserved to guard us from ubiquitous bacteria. The receptor, although known to exist but previously unidentified, plays a critical role in sensing the presence of bacteria to initiate a response. The importance of this finding is evidenced by the original paper being cited over 5500 times.[2] None of the photos taped to the pages on display in the notebook made their way to the final Nobel Prize-winning publication, which is not unusual since researchers usually redo experiments to confirm their data, but the "TOLL, TOLL, TOLL" written across the top captures the specific "eureka!" moment that stirs the imagination of any young aspiring scientist. Unfortunately, few visitors to the museum would be aware of this significance when viewing the notebook.

Originally a record-keeping device for the development of new scientific knowledge, the Beutler notebook is transformed by its context in the Perot Museum into a token of achievement. While the Beutler notebook *does* celebrate the results of a successful research process, it also draws attention to that process—and the fact that research takes time, includes failures as well as successes, and is rarely a singular and objective 'aha' moment—just think of all the pages written before and after the experiment that led its

2 A. Poltorak, et al. "Defective LPS Signaling in C3H/HeJ and C57BL/10ScCr Mice: Mutations in Tlr4 Gene." *Science* 282.5396 (1998): 2085-2088.

author to scribble a victorious "TOLL, TOLL, TOLL." Although the researcher who wrote those words in the notebook clearly knew the data was significant, he or she did not know at that time that it would result in a Nobel Prize. Instead, the Beutler notebook and other scientific notebooks included in public displays draw attention to the gray areas of science, and make the public aware of the importance of data that must be interpreted before drawing conclusions and enacting new solutions.

Lab notebooks in the lab

Part of the Beutler notebook's significance lies in the fact that it is not just a regular notebook, but a *laboratory notebook*. Laboratory notebooks fill multiple roles in the scientific research process, the most obvious of which is as a record. Importantly, lab notebooks track procedures as they occur and collect the raw data, such as the photographs of electrophoresis gels in the Beutler notebook. Like any researcher's notes, lab notebooks include much more than what is eventually included in a published article or presentation, because the ideas and data must be synthesized to form conclusions. A lab notebook acts as a second brain for the researcher by maintaining detailed protocols of experiments for future reference and troubleshooting; a chronological account of progress made; and a repository for data acquired. Beyond the research itself, the lab notebook is the basis for claims of intellectual property as well as an invoice to funding sources for work done. For these reasons, lab notebooks are *more* than a record or diary of one's path to discovery; they can be messy, repetitive, full of failure, and sometimes, as in the Beutler notebook's exclamatory, "TOLL, TOLL, TOLL!" include nuggets of discovery.

Although lab notebooks are records kept often by only one individual in that lab, they serve the lab as a whole. The Beutler notebook on display, for example, was kept by one researcher, yet it is the property of the lab itself and there are likely many notebooks that preceded and followed it with similar research. Notebooks can provide continuity as members of a lab (e.g., graduate students or postdoctoral fellows) cycle in and out, and provide a record for the research activities of that lab, in which many projects are likely occurring at one time. Some of the stringent record-keeping required for lab notebooks reflects their purpose not only as documents of process, but documents of proof. In some instances, pagination is used to ensure no pages have been removed from the book or lab. Dating every page provides proof of when certain experiments were done and conclusions were made. In industry labs where intellectual property challenges can cost millions or billions of dollars, pages are signed by a supervisor to witness the veracity of the basic information such as date and page number. These policies may seem overly cautious, unless one keeps in mind that lab notebooks can potentially serve as the main proof of discovery for patents, prizes, and funding. The research—good and bad—is not private, but recorded for the possibility of future scrutiny.

Although lab notebooks are by definition not private, most researchers, including the scientist who scrawled "TOLL, TOLL, TOLL" would never expect their notebook to end up on display for public consumption in a museum setting, largely because they are considered part of the research process. Data, notes, and observations included in a lab notebook are raw and require context, synthesis, and interpretation before conclusion can be made. A lab notebook is not itself a final product, but a tool in the research process. When combined with additional tools—additional research, comparison with

other scholarship, analysis—it can serve as evidence for conclusions. It is rare for researchers to publish a notebook itself as evidence, and often researchers will redo experiments to get 'cleaner' data for publications. The photos in the Beutler notebook, for example, are not published in the final paper. The rapid expansion of information storage, as well as the push for transparency, has led researchers to include even more data, meaning that the imperfections of a lab notebook are less objectionable. In 2011, Gregory Lang and David Botstein, for example, published a scanned version of their entire lab notebook for a paper in the journal PLOS ONE, a move that emphasizes the importance of the notebook itself, but diminishes the subsequent processes of synthesis and interpretation.[3]

Of course, the act of recording, synthesizing, and analyzing as part of the research process is not exclusive to the biosciences, but is important in many disciplines. In his recent account of field notebooks, naturalist Michael Canfield makes the case that field scientists have developed a sort of hybrid notebook that is unique to their discipline and research process. This hybrid notebook is equal parts journal, illustration, and documentary, and it has evolved to fit the specific act of research, which largely means observing nature. In many ways, the efficacy of these notebooks relies largely on their being handwritten and hand-drawn, making them in some cases closer to a diary or even sketchbook.[4] The modern lab notebook has precursors in field notebooks—the most famous field notebooks are probably those of Charles Darwin from his 1835 expeditions on the *H.M.S. Beagle*, which are not full transcripts of his journey and everything he planned to do, saw, or recalled, but limited to his important observations, notes, and drawings. Darwin later used field notebooks to piece together his full conclusions, in some cases with the help of other scientists at the University of Cambridge. While this more painstaking and process-oriented research shatters what we may have imagined as Darwin's 'aha' moment while visiting the Galapagos and observing the finches or tortoises, it is very much in line with how the modern lab notebook is used in the research process: plan, execute, gather data, synthesize, and draw conclusions.

Lab notebooks in the museum

Given the very specific purpose of a lab notebook, why display the Beutler notebook in the museum and how does its purpose change in this new setting? At the Perot, the Nobel installation is part of the museum's "Being Human Hall," which is described on the website as "the story of YOU" where visitors will "be transported through the human journey as [they] explore the traits and abilities that are essential and unique to being human." Installations in the Hall range in topic from DNA to the human brain to a virtual reality experience of a South African cave where researchers found the *homo naledis* species in 2015. The Nobel installation greets visitors and serves as a sort of introduction to the world of scientific discovery and achievement. According to Mike Spiewak, Director of Exhibitions at the Perot, the exhibit was the brainchild of Nobel laureates Gilman and Diesenhofer, who approached the museum looking for a way to inspire younger generations to be interested in science and thinking that the Perot could

3 G. Lang "A Test of the Coordinated Expression Hypothesis for the Origin and Maintenance of the *GAL* Cluster in Yeast," *PLoS ONE* 6.9 (2011): doi.org/10.1371/journal.pone.0025290.

4 M. Canfield. ed. Fieldnotes on *Science and Nature*. Harvard University Press, 2011.

provide an appropriate platform. Gilman, Spiewak recalls, shared his own story about being inspired by the New York City planetarium as a child.[5] Spiewak developed an earlier iteration of the current installation, working one-on-one with the scientists to understand their backgrounds, personal journeys, and projects. He explained that they wanted to excite young people and make the concept of scientific research more accessible to the general public. In that context, the notebook is not presented as a resource for the scientific discoveries, (for this purpose, one would do better to reference the resulting paper published in *Science* in 1998) or to establish the intellectual property for the discovery it contains (the Nobel prize on display in front of the notebook's case is likely sufficient for this goal). Besides serving as a token of Beutler's scientific achievement, why choose the lab notebook?

The Beutler notebook is the only object in the Nobel display that is original and from the actual research process—it is, in effect, an artifact. The Perot Museum's vision is to "be an extraordinary resource and catalyst for science learning through innovative, highly accessible experiences that broaden understanding of our world," and that mission of accessibility is highlighted in the display of the Nobel laureates. According to Spiewak, each laureate emphasized their desire to invoke the feeling for visitors that "this could be you." To convey that, alongside the prizes and other objects is a screen that rotates through the five laureates' images. There, Beutler's image is shown paired with a quotation that reads, "Just like a prospector finding gold, I knew we had found it." In some ways, the lab notebook drives home this metaphor of momentary discovery— with the "TOLL, TOLL, TOLL" inscription, it records the researcher's notably unique moment of

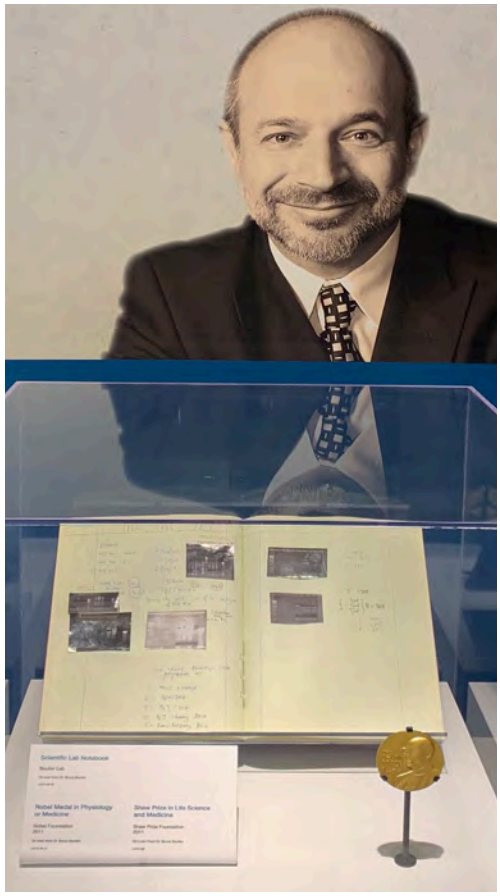

Figure 2 Installation view of the laboratory notebook from the lab of Dr. Bruce Beutler at the Perot Museum of Nature and Science, as displayed 2020. Copyright Perot Museum of Nature and Science.

realization, but at the same time, the object itself makes this moment tangible. A visitor does not have to imagine an abstract or complex concept, such as a specific protein, but can understand, by viewing the physical object, what it must have been like to make this discovery.

The impetus to collect, and even display, scientific objects, artifacts, and writing is not a new one, but something whose development mirrors the development of science itself. In antiquity and the medieval period, the desire to understand the natural world by cataloguing and collecting was evident in the writings of naturalists such as Pliny or Galen,

5 Personal correspondence with Michael Spiewack, May 14, 2020.

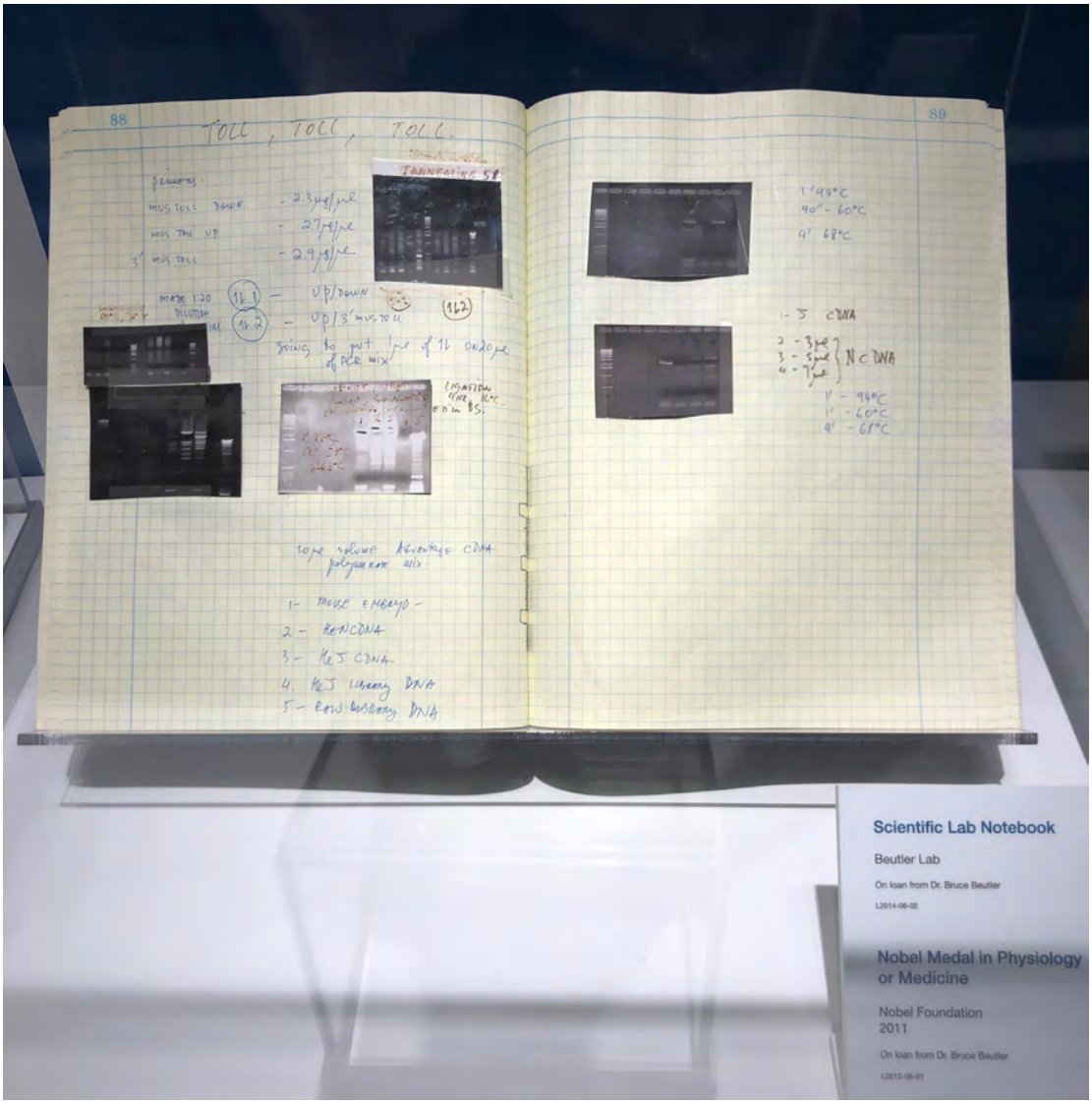

Figure 3 Detail of the laboratory notebook from lab of Dr. Bruce Beutler in the Perot Museum of Nature and Science. Photo by Elizabeth Molacek. Used with permission of the Perot Museum of Nature and Science.

as well as mathematicians such as Ptolemy, whose work attempted to make sense of the natural world by categorizing or theorizing. The work of these early naturalists was collected by educated individuals throughout Europe during the sixteenth and seventeenth centuries. As the world became increasingly global, knowledge in many forms began to be spread more widely, so that collecting scientific material and objects became an important means of displaying evidence of such knowledge, even if it became increasingly impossible for one person or group to understand it all. These personal collections took the form of cabinets of curiosities, or *wunderkammer*, which skewed

towards the exotic, rare, and luxurious. They were less scientific than carefully curated miniature universes emphasizing the wealth, intelligence, and knowledge of the aristocrat who amassed the collection. These aristocratic curiosity cabinets eventually gave rise to natural history museums, which were still different from what we find today at the Perot Museum—they were more focused on making sense of the natural world through empirical observation and objects or artifacts. Over the course of the 18th century, science became a more defined discipline, meaning that museum collections continued to acquire and display objects—including scientific books—in a more focused way, reflecting the increased emphasis on empirical observation and rigorous research methods.

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Many scientific notebooks and treatises could be considered some precursor to a modern lab notebook and are popular items for display in history, science, and even art museum collections—perhaps emphasizing their role as artifact. The Codex Arundel in the British Library (MS Arundel 263), for example, is a diary-like compilation of Leonardo's drawings, writings, and scientific observations from throughout his life, concerned primarily with mechanics. The codex was gathered and bound *after* Leonardo's death, however, and thus cannot be considered a real-time documentation of processes or discoveries. Today the codex is treasured more as an artifact of Leonardo the genius or for the drawings that it contains, an example of the object or artifact far outshining the scientific content or discovery. In contrast, some lab notebooks are collected more as historical records. An example of this might be Marie Curie's personal lab notebooks, now in the Bibliothèque nationale de France, which were used for the preparation of her thesis *Recherches sur les substances radioactives*, published in 1904, which led to her first Nobel Prize in Physics (she went on to win a Nobel Prize in Chemistry in 1911). Although these notebooks are certainly a far cry from the beautiful, sketch-like notebooks of Leonardo, and filled with scientific content that moved the field forward, they are extremely inaccessible to the public both intellectually and physically—they remain radioactive and can only be seen under special circumstances and after donning the appropriate protective gear, making the lab notebooks almost exclusively a token of achievement.

Marie Curie's radioactive notebooks are an extreme example of a scientific token, but many museums of the history of science and rare books libraries do maintain collections of more modern lab notebooks that serve as teaching resources or references for intellectual history. The British Library, the Museum of the History of Science at Oxford University, and Harvard University's Center for the History of Medicine, among others, now collect what could be considered modern lab notebooks, including those of current professors, which can be accessed for research purposes. What remains slightly less common is the display of such notebooks in a museum environment, particularly as objects of *inspiration* for a more general public—such as we find with the Beutler notebook in the Perot Museum. One recent instance was the 2016 special exhibition at the Melbourne Museum *Biomedical Breakthroughs: A New View of You* that included several lab notebooks

from Australian Nobel Prize winner Sir Frank McFarlane Burnet, who won the prize in 1960 for his work on immune systems. The notebooks were displayed along with other objects that could help tell the story of scientific progress, but the goal of the exhibition was to, "shake up [the visitor's] old view of science by showing biology as colourful and dynamic."[6] This goal was achieved by including a huge number of interactive, artistic, molecular animations created by an artist-in-residence at the city's Walter and Eliza Hall Institute of Medical Research. In this context, Burnet's notebooks played a similar role as the Beutler notebook: they engaged visitors in the scientific process by highlighting scientific *progress*.

The future of scientific discovery in the public sphere

The Beutler notebook is a clear instance of the scientific process on display in a public forum; however, it is an artifact and the knowledge within it is no longer novel, nor actively contributing to new ideas. Beyond the museum, lab notebooks continue to be vital tools as research plays out in the public sphere. Recently, two high-profile articles discussing hydroxychloroquine as a treatment for COVID were retracted from *The Lancet* and the *New England Journal of Medicine*, for the absence of supporting data from lab notebooks. A third-party auditor was denied access to the raw data used for both papers by the company that had collected it, Surgisphere, whose founder was listed as a co-author. Surgisphere claimed that sharing the data violated confidentiality requirements. In other words, they refused to share their *lab notebook*. The ability to verify original data is so inherent to the scientific process that the other co-authors elected to retract their publications, in effect confirming the importance of a scrutinized process in the semi-public research setting.

The COVID crisis is a dramatic instance of heightened awareness and interest in medical research, but the issues it raises—the need for scientific literacy and the role of museums or other accessible collections in building this knowledge—is relevant far beyond the pandemic as information becomes increasingly available and transparent. Just as the cabinets of curiosities were the 16th century solution for processing a surge in new information, the public today is discovering ways to collect, sort, and absorb the deluge of data. Museums like the Perot continue to explore *how* we acquire knowledge rather than just the knowledge itself, equipping visitors with tools to digest information in the public sphere. Nonetheless, the sheer volume of new research and data remains impossible for even the most avid individual researchers to keep up with. The journal *Science* estimated that 23,000 new COVID-related papers alone were published between January and late May, with that number expected to double every 20 days.[7] What could this mean for the interested public and how does it affect the way we intersect with new scientific knowledge? One signal might be CORD 19, which is an effort to "curate and archive" a "growing resource of scientific papers on COVID and related historical coronavirus research." This effort, partly funded by the Chan-Zuckerberg Initiative, uses AI tools to explore the scientific literature, by methods such as extracting information from large amounts of published data or investigating visual patterns between sets of published

6 J. Bailey. "Biomedical Breakthroughs takes close look at our bodies at Melbourne Museum," *The Sydney Morning Herald*. August 19, 2016.

7 J. Brainard. "Scientists are drowning in new COVID-19 papers. Can new tools keep them afloat?" *Science*. May 15, 2020. www.sciencemag.org/news/2020/05/scientists-are-drowning-covid-19-papers-can-new-tools-keep-them-afloat.

texts. Making huge amounts of data available, curated by AI, offers a potential, albeit controversial, solution for bridging the divide between laboratory and public, creating a collective "laboratory notebook" for the world's processing of COVID. And while it is unlikely that most of us will experience the 'eureka' moment that Bruce Beutler and his lab felt when they scrawled that excited "TOLL, TOLL, TOLL" across the top of the notebook, perhaps mining these available sources will give us a small sense of discovery—like a prospector finding just a dusting of gold. *A*

Further Reading

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